REPORT

OF

THE SECRETARY OF THE NAVY,

In compliance with a resolution of the Senate, in relation to the invention of Thomas S. Easton, for preventing explosions of steam-boilers.

June 24, 1842.

Read and referred to the Committee on Printing.

June 25, 1842.

Ordered to be printed.

Navy Department, *June* 23, 1842.

Sir: The resolution of the Senate of the 15th of April last requires me to select "some suitable person or persons, whose scientific knowledge upon such subjects may render him or them competent to the performance of such duty, to examine the recent invention of Thomas S. Easton, to prevent the explosion of steam-boilers, and to report the result of said examination to the Senate with the least practicable delay." I have the honor now to report that, immediately after the passage of the resolution, I intrusted the execution of it to Professor Walter R. Johnson, who readily undertook that duty, and entered upon the performance of it without loss of time.

The result I now communicate in the accompanying report from him to me.

It will be perceived that the experiments made by Professor Johnson, with a view to test the practical operation of Mr. Easton's invention, have been very numerous, and that they have been conducted with great care and attention. His high character as a man of science, and his known diligence and accuracy in the prosecution of scientific inquiries, authorize the belief that the results, as he has reported them, may be relied on with entire confidence. He has thrown much additional light on the nature of certain substances used for preventing explosions, and which have been relied on with a confidence not justified by the state of information in regard to them. As incidental to the main inquiry, he has given a new verification of the pressure of steam at different temperatures, a subject which it is of the utmost importance to understand, with reference to any invention for preventing explosions in steam-boilers.

The objections to Mr. Easton's invention appear to me to be stated with great clearness and impartiality.

The introduction of steam-vessels into the navy of the United States, increases the importance of those scientific researches into the nature and properties of steam, which may enable us to manage and control that powerful and dangerous agent. A great variety of inventions for preventing explosions, have been presented to this Department, many of which, it is presumed, would offer valuable suggestions to a mind sufficiently imbued with the science of the subject. There are not, however, within the control of the Department, any means of testing these inventions in a satisfactory manner, and consequently much useful information may be thus lost to the world.

The valuable information furnished by the report of Mr. Johnson, may be received as a new proof of the importance of enabling the Department to command, at all times, the talents and learning necessary for conducting these researches in practical science, upon which depend so much of public and private interest. It is confidently believed that, independent of all higher considerations, the saving, *in money*, in this Department alone, by a proper application of the tests of natural science to the various materials used in the building and equipment of vessels, would greatly exceed the salary necessary to command the best talents and qualifications for that service.

I have the honor to be, with great respect, sir, your obedient servant,

A. P. UPSHUR.

Hon. W. P. Mangum,
President of the Senate.

Washington City, *June* 22, 1842.

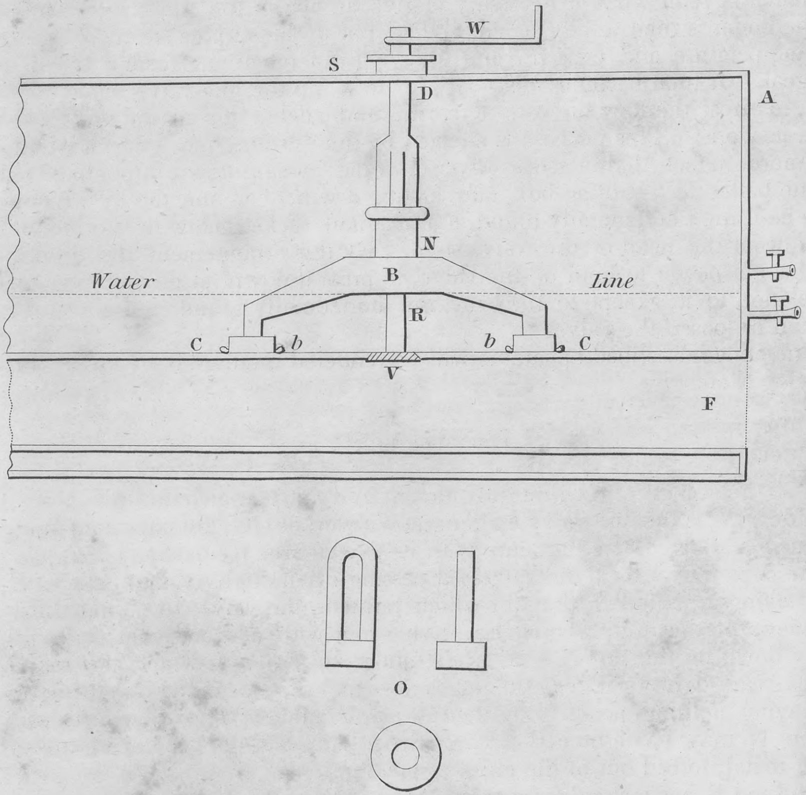
Sir: In conformity with your desire, conveyed to me in your letter of the 21st of April last, accompanying a resolution of the Senate of the United States, of the 15th of the same month, requiring an examination of the recent invention of Thomas S. Easton, to prevent the explosion of steam boilers, I have the honor to state that, on the reception of your communication, I proceeded to execute, with the apparatus previously established by the inventor, in the building belonging to the Patent Office, a number of experiments, to prove the practical working of the plan proposed.

The apparatus which I have used is described in the specification of Mr. Easton's patent, and is defined in the *claim* attached to that specification, which is in the following words:

"What I claim as my invention is the flue safety-valve, acted on by fusible metal, which will let it down at any required degree of heat or steam-pressure, alike protecting the steam-boiler from bursting, or its flue from collapsing; and I also claim the driving-rod; for which invention, I desire to secure my right by letters patent—the flue-valve and the driving-rod being in conjunction."

The apparatus above referred to, as the "flue safety-valve," is a conical valve, in the top of the flue, opening downward, so that the contents of the boiler are discharged through it, into the flue, whenever the supporting rod above, which is within the boiler, ceases to be sustained. The manner of sustaining this rod is to cause it to traverse an up-curved brace or yoke, similar to that which is in general use to keep in place the closing plate in the manhole of a steamboiler.

The lower part of the valve-stem, where it joins the valve, and for some distance above, is square, in order to pass through a square hole in the top of the yoke or brace. The upper end of the rod, for about two inches in length, is cylindrical, and has a screw cut on it to receive a nut coming down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on the same so as to hold *it*, together with the valve, firmly in place, resting on the cross-brace, the feet of which, in turn, rest on disks of fusible metal contained in two metallic cups or rings placed on the top of the flue. These cups or rings have each one or more openings near the bottom, through which, when melted, the fusible metal may escape, being urged out by the pressure brought upon the brace by the valve, which is attached to, and depends solely on it, for support.

Whenever the pressure of steam, with the corresponding temperature, by rising too high in the boiler, has caused the melting of the disks, or their softening, so as to allow a part of the metal to be forced out, the brace, valve-stem, and the valve itself, are allowed to fall a little, so as to open a passage for the water or steam to escape. In order to prevent the discharge of the contents, beyond what is necessary to give an alarm, the main safety-valve of the boiler is then to be opened, giving exit to the surplus steam, lowering the temperature and pressure, and allowing the remaining fusible metal to congeal. It then becomes necessary to draw up the flue-valve again to its seat, to arrest the flow of water or steam, and enable the engine to proceed with its work. This purpose is effected by the "driving rod," which is nothing more, in fact, than a screw-driver on a rod, passing down through the top of the boiler in a stuffing-box, and having a winch on the top by which it may be turned horizontally round, and a square socket below to take hold of the nut on the head of the valve-stem. By this arrangement, the driving-rod has no power to hold up the valve, to press it down, or do anything else in relation to it, except to turn the nut horizontally round, and thereby to tighten or loosen the valve.

The above described apparatus will be rendered intelligible by the accompanying sketch.

[See diagram.]

A, is the section of a cylindrical boiler, with an interior return-flue. F, is the flue. V, is the flue-valve opening downward. CC, are cups containing the fusible alloy. B, is the brace with its two circular feet resting on an alloy in the cups CC. R, is the valve-rod passing up through a square hole in B, and having at its top N, the nut which tightens the valve. O, three different views of this nut. D, is the driving-rod, with a square socket to slip easily down on the nut N. S, is a stuffing box, through which the rod D passes steam-tight. (The tightening screws and caps are omitted in the figure as having nothing peculiar in their construction.) W, is a winch, with which N may be tightened or brought to its bearing. *bb*, are beads of fused metal, forced out of the cups by pressure.

The rod R has a shoulder, terminating the threads of the screw to which N is adapted, at a distance above the top of the flue, greater than the height of the brace B. This shoulder limits the distance to which the brace can be driven down.

The boiler, to which this apparatus is attached, and which was employed in my experiments, is about $3\frac{1}{2}$ feet in length, 20 inches in diameter, with an interior flue $8\frac{1}{2}$ inches in diameter—made of $\frac{1}{4}$ inch plate-iron, with heads of the same material. It had a safety-valve of the ordinary construction, and a hand-hold by which access could be had to the interior.

It is evident from the above description, that the pressure exerted by the two feet of the brace B, upon the fusible metal in the two cups CC, will be precisely equal to the total pressure on the valve V, added to the unimportant weight of the brace, valve, and nut. These latter may, for all practical purposes, be considered null, as their whole weight does not exceed one or two pounds.

The inventor does not specify any particular proportions to be used, between the size of his fusible disks and that of his flue-valve. In the apparatus as arranged, during the principal part of the experiments herein detailed, the flue-valve had a diameter of .91 inch, and each disk 1.25 inch, making the *area* of the disks 3.83 times as great as that of the valve which they supported; so that the effective pressure on a square inch of the fusible alloy was, at every experiment made in connexion with this arrangement, 1-3.83, or say *one fourth*, as great as that exerted on a square inch of the inner surface of the boiler, *above one atmosphere.*

In two sets of experiments, the diameter of the disks was diminished to $\frac{3}{4}$ of an inch, thus increasing the relative pressure on the square inch of alloy, to 1-1.36 part of that on the boiler surface. This arrangement afforded an opportunity of determining, in part, the influence which the *degree of pressure* may exert on a given alloy, when employed in the manner proposed in this apparatus.

From the foregoing remarks it is obvious that Mr. Easton's is one of those inventions which rely for their efficacy in giving alarms, when danger of explosion approaches, on the combined agency of heat and pressure upon fusible compounds. It is the professed design of the peculiar arrangement, fixing the apparatus in the interior of the boiler, to prevent either accidental or wilful interference with its action, while under the application of steam.

The following extract from the memorial of Mr. Easton to Congress, on the subject of his apparatus, exhibits his own confidence it its certainty and uniformity of action, and may probably have had its influence in determining the Senate to cause the examination called for by the resolution, under which this inquiry has been instituted:

"This mode consists in the peculiar disposition and use of a safety-valve, which, in its operations, is subjected to the control of principles as fixed, certain, and inevitable in their action, as anything in physical science, and which is placed entirely beyond the control of the engineer, or any one connected with the machinery during the process of steaming, and is made to constitute a part of the inner structure of the boiler and fire-flue."

The application of fusible metals to steam-boilers, as a means of safety, dates at least as far back as the 29th of October, 1823, when the first important ordinance in relation to this subject was promulgated in France.

The directions for preparing and fixing on the disks, were not, however, published until the 7th of May, 1825; the intervening period having been occupied in researches relative to this and other branches of the subject of explosion. An important character of fusible metals was distinctly recognised in the last-mentioned ordinance, in which it is directed, that, "in verifying the degree of fusion of fusible metals, the engineer must keep in mind that the question is not to determine the degree at which the metal becomes perfectly fluid, but the point at which it softens sufficiently to give way under the pressure of steam. This distinction is of importance, for the disks of fusible metal are susceptible of losing their tenacity a little before reaching the temperature that determines their final fusion. The *stamp* must consequently express, not the degree of perfect fusion, but that which softens the metal sufficiently to render the disk susceptible of giving way under the pressure it will experience at that temperature."

The ordinance requires that two disks shall be inserted in the top of every steam-boiler, one having a melting temperature, ten degrees centigrade, (18 deg. Fah.), and the other twenty degrees centigrade (36 deg. Fah.) above the temperature of the steam, corresponding to the maximum load allowed on the safety-valve.

As these disks are acted on both by heat and pressure, it may be of interest to know what experience has taught in regard to the certainty of preventing explosions by fusible metals, when applied in this way. In a recent publication,* is found an account, given by a distinguished engineer-in-chief,† of mines in France, detailing not less than seven different explosions of steam-boilers, of which minute descriptions had, between 1837 and 1841, reached the department of public works. Of the exploded boilers, it appears that *five* had had fusible disks, attached in conformity with the ordinance above cited.

In neither case, however, did it appear, after the explosion, that the disks had been melted. In one instance, the more fusible of the two was found dotted over with globules of metal, which had oozed out of the pores, indicating the high pressure to which it had been subjected, forcing out the more fusible parts of the compound. The mass of unmelted metal was also partly forced into the interstices of the grating of infusible metal, placed over the disk to prevent its bursting at pressures below that corresponding to its melting temperature.

In another instance, the disks were still solid, but the more fusible had been compressed into the interstices of the confining grate, and the bubbles of exuding metal were more than one fourth of an inch in height. The less fusible disk was barely distorted a little from its original shape.

In a third case, which was that of a steamboat making (like the Medora) her first trial trip, the two fusible disks were found, after the explosion, to have been entirely unaffected by the accident.

The experiments of Rudberg, confirmed in all their principal features by others subsequently made in this country, have pointed significantly to the cause of these phenomena.

It is, in fact, ascertained, that when simple metals are mixed and fused in different proportions, they give rise to compounds which are fusible at various lower temperatures than the mean fusing point of the simple metals themselves.

These compounds, in their solid state, may be not inaptly compared to sponges which have been allowed to imbibe a quantity of melted tallow or other similar liquid, which on congealing will, with the sponge, constitute a mass of a certain degree of hardness, and when melted will, by capillary attraction, be still kept in its pores, but which can, by the combined effect of warmth and pressure, be forced out at a temperature which will leave the sponge wholly uninjured. There is also a strong analogy between fusible alloys and certain natural products of the animal and vegetable kingdom, particularly such as yield fixed oils and expressed juices. Lamp oil and spermaceti are two well-known substances, derived either by pressure alone, at common temperatures, or by the combined agency of heat and pressure, form a mass which is at first semifluid and granular at ordinary tempera-

* Annales des Mines, tome 20 (iv. livraison for 1841), page 113.
† M. Ch. Combes.

tures, but which the manufacturing process separates into a liquid that will remain such at very low temperatures, and a hard dense solid, which remains in that state when heated much above the point which kept the original mixed mass in complete fusion. In this case, as in that of metallic alloys, different compressing forces at the same temperature, and the same compressing force at different temperatures, may separate the original mixtures into variable proportions of liquid and solid product. In Mr. Easton's invention, the pressure on the fusible alloy increases simultaneously and in a certain proportion to the increase of temperature. The actual pressure at each temperature may, as already stated, be varied at pleasure, by varying the relation between the size of the flue-valve and that of the two disks.

The question which remained for experimental determination was, what proportion of the several alloys, appropriate to such a purpose, could be relied upon to melt and be forced out within a reasonable range of temperatures, and capable of giving a succession of results, which would not, on the one hand, prevent the engine from proceeding with its work after a single alarm, or on the other, render subsequent indications of danger, too uncertain for reliance.

If the metal could all escape from the cups at a single operation, and thus allow the nut on the top of the valve-stem to be at once brought to the shoulder on the rod, the valve could no longer be drawn up to its seat—the contents would escape from the boiler, and the engine must stop. In this case, the first condition would fail to be fulfilled. In none of my experiments did this result take place. It is true that the action of the apparatus was always attentively observed, and prompt measures were taken to arrest the flow of water from the flue-valve, as well as to raise the safety-valve, and thus lower the temperature and pressure of the steam, to allow the semi-fluid metal again to become solid and support the valve below.

As to the other contingency, that of rendering the alloy unfit for repeated actions, the experiments will show what degree of uncertainty attended the employment of the several alloys. In not more than one instance did the action of the alloy continue uniform through the entire series of experiments made with it. With unimportant exceptions, there was a constantly increasing pressure and temperature required to cause a series of actions of the flue-valve to take place. In some instances, two, three, or more consecutive actions would take place under sensibly equal pressures. In a few instances, while the heat was rising rapidly in consequence of a vigorous combustion on the grate, the temperature and pressure of the steam would rise above the true fusing point of the alloy. This was caused by the gradual, not instantaneous reception of the latent heat of fluidity in melting bodies. The alarm given by the flue-valve would, in that case, seem to be produced at too high a temperature, and subsequent actions were obtained with a slower combustion, at pressures one or two pounds per inch lower than that which had preceded. Cases of this kind are rare. In order to cover the whole range of pressures believed to be admitted in steamboat boilers, the experiments took a range from about 20 pounds to more than 157 pounds of pressure per square inch on the safety-valve, employing, of course, different alloys to serve at the several points on the scale.

The interior or smaller base of the safety valve contained an area of one square inch. By attaching a wire to the stem of this valve, and suspending it to the hook of a Dearborn's patent balance, its own weight, together with that of the lever, was accurately ascertained, as well as the effective weight on the valve, produced by every weight applied on any part of the arm of the lever in the course of my experiments. By this method of determining the pressure on the safety-valve, all uncertainty, however slight, arising from calculations respecting the length of the arms of the lever, was avoided.

Having tried a pair of cups filled to a known height with a given alloy, and ascertained what number of times it would permit the flue-valve to act before the metal became too hard to allow the continuation of the series without a great increase of heat and pressure, or before it was so far exhausted that the nut came to the shoulder of the valve-rod, the experiment was discontinued, the steam let off, and the fire extinguished. The residue of the disks, the beads of metal adhering to the bottom of the cups, and the portions of exuded alloy which had fallen and run together in the bottom of the boiler (usually found in two large buttons or plates), were then withdrawn, and, together with a sample of the alloy taken from the cups at the time of casting the disks, were laid aside with a view to examine their respective melting temperatures. This latter process served to indicate the character of the several products.

In taking the melting or rather the congealing temperatures of these alloys, a bath of oil was employed having a shallow iron cup containing the sample of alloy to be tried plunged so far below the surface as to be on a level with the bulb of a thermometer used to note the temperature. The bath containing the oil and cup of alloy was heated till the latter was in perfect fusion. It was then withdrawn from the source of heat, and observations by the thermometer were commenced. It was sought to determine when the fluidity of the metal received its first check by the formation within the mass of any angular particles—the rudiments of a crystalline structure, which, in every case, will precede the solidification of the alloy. This can be known only by agitating the melted globule or mass, and by means of a rod drawing out from its edge rings of the liquid. As long as these rings break readily, and return into the common mass preserving a perfectly smooth contour, the fluidity is considered perfect. When, on the contrary, the drawing out of a ring from the periphery of a globule, shows the least roughness or angularity, it is certain that solidification is about to commence. The button of melted metal, in the meantime, if left to itself, would have exhibited no symptom of congealing, and even if shaken from side to side of the cup, it would have given no signs of what was going on within. Beside the point just mentioned as marking the temperature of the bath at which fluidity is diminished, other stages were noted, particularly that at which an impression made in the metal, or an accumulation formed by the rod, ceased to be wholly obliterated by the return of the now semifluid metal to a level surface and uniformly rounded figure; the metal was then said to be "permanently impressed." This is the point at which the solid begins to predominate over the liquid portion of the semifluid substance. When in this state, and for some time after it commences, a small cavity formed in the mass will immediately be filled with a little pool of liquid, and if pressure be applied while the mass is in this state, a quantity of the more fluid portions will be forced out. After these pools *cease to be formed*, the alloy will still retain so much of the liquid diffused among the granules of solid metal as to be capable of recementing or soldering together portions that have been separated by force. The temperature at which this was done was usually noted as one in which the alloy, having been brought to the state of a very brittle soft solid, the sandy particles, into which the button would be separated, ceased altogether to cohere. A lower stage still, and the last noted, was that in which the metal was hard enough to resist penetration without the application of much force.

It is obvious that all the stages above noted have a more or less direct bearing on the various uses of fusible alloys, in connexion with the means of preventing explosions. The fluid and semifluid states are those in which apparatus intended to force out the liquefied portions can alone become efficient. The granular or slightly-cohering state allows mobility without actual fluidity, yielding to the exertion of very moderate forces, and is applicable to other forms of apparatus.

A remark of some interest occurred in taking the temperatures of various alloys of lead, tin, and bismuth. It related to the different manners in which the several portions derived from the same mixture by heat and pressure, behaved toward the olive oil in which they were immersed. When the metal possessed a large proportion of bismuth the melted globule, if heated much above its melting point, would become covered with a bluish black pellicle of oxide, apparently that of bismuth, which dulled its aspect, and rendered minute accuracy in determining the commencement of granulation more difficult than it otherwise would have been. This was especially the case when the part under trial was either the original alloy or the residuum of the disks which had become too thin or two hard for further use.

The expressed or exuded metal, on the contrary, contained in the beads adhering round the bottom of the cups, and the plates which had fallen and run together on the bottom of the boiler, retained, in general, their lustre nearly unimpaired, unless at very high temperatures. When the black film just noticed was agitated by stirring the globule with a rod, it gave rise to a distinct appearance of cloudiness in the oil, attended with minute metallic particles suspended in the liquid, which thus became, by degrees, changed in color from a yellow to a greenish tint, due to the solution of the oxide and the formation of an oleate of bismuth, of lead, or of both.

It seems probable that the freedom of the expressed and highly fusible compounds from this action of the oil, when in a state of fusion, may be due to their being true chemical compounds, and not containing a mechanical mixture along with the alloy. Alloys of tin and bismuth, in the proportion of 10 of the former to 12 of the latter, and also with these proportions reversed, were found to receive a similar bluish black pellicle when fused in the steam-boiler.

It was not observed that any of the alloys, after being completely formed and remelted, exhibited either in oil or in the open air any decided evidences of oxidation until their temperature had risen above the point at which they become soft. In most cases the heat rose much above the point of perfect fluidity before any signs of this effect were noticed. No evidences of oxidation, taking place in the cups while exposed to alternate softening and hardening in the boiler, were discovered.

In giving an account of the several experiments performed with this apparatus, it will be unnecessary to detail the minute particulars of every series, as this would give rise to much repetition in regard to precautions which were in all cases adopted to avoid error.

FIRST SERIES.

The first trials were made on disks previously prepared by the inventor. A pair of these, stated to be composed of six parts, by weight, of tin, and four of bismuth, was placed on the flue; the boiler properly filled with water, so as to be several inches above the top of the flue, the aperture closed, and a brisk fire kindled. The temperature and pressure of the steam rose with considerable rapidity, but not such as to prevent the weights, under which the flue-valve began to act, from being duly observed. The valve acted, and the water was discharged into the flue for the *first* time under a weight of $89\frac{1}{2}$ pounds on the safety-valve.

The *second* time under a weight of		$97\frac{1}{2}$	pounds on the safety-valve.	
The *third* "	"	$117\frac{1}{2}$	"	"
The *fourth* "	"	$119\frac{1}{2}$	"	"
The *fifth* "	"	116	"	"
The *sixth* "	"	116	"	"
The *seventh* "	"	$121\frac{1}{2}$	"	"

This shows an increase of thirty-five per cent. in the amount of pressure produced by seven successive actions. On taking out the disks after cooling off the boiler, they were found to be still between one and two tenths of an inch in thickness. They were replaced, and having replenished the boiler, steam was again raised to 120 pounds of pressure. As no action of the flue-valve occurred for ten minutes while the steam was allowed to escape under the weight, the pressure was increased to 130 pounds. After seven minutes, the flow of steam increasing as the heating went on, the flue-valve gave indication of the softening of the alloy. The safety-valve was now, as in all the previous trials, raised to allow the escape of steam, in order to reduce the pressure and harden the metal before screwing up the flue-valve. After doing this, the weight on the safety-valve was replaced at 130 pounds, and, under this weight, the steam was allowed to escape for ten minutes, when, as no sign of opening the flue-valve occurred, the weight was increased to $143\frac{1}{2}$ pounds, under which the steam escaped for seven minutes, when a *second* action of the flue-valve occurred. After discharging steam to reduce the pressure, and screwing up the flue-valve, the weight on the safety-valve was replaced at the same point, but no action having occurred in five minutes, the weight was increased to $148\frac{1}{2}$ pounds. In about three minutes a slight discharge of water through the flue-valve occurred, when it was tightened without raising the safety-valve, the weight was increased to $153\frac{1}{2}$ pounds, and under this, steam escaped for five minutes without any further action of the flue-valve. As the gauge-cocks now showed a deficiency of water, the experiment was discontinued, and after cooling the boiler the cups were once more examined; a very little of the alloy had been pressed up round the feet of the brace, but the chief part of what had escaped had evidently been forced out of the two notches in the bottoms of the cups.

The disks were taken out of the cups and examined. That surface of each which had come in contact with the iron of the flue, exhibited a coarse granular texture. The thickness of one of the disks was one quarter of an inch; that of the other, .17.

As the pressures required to produce the successive actions on the flue-valve had increased, from the first to the last trial, from $89\frac{1}{2}$ to $153\frac{1}{2}$ pounds or 71.5 per cent. over the initial experiment, it was evident that, if this series of trials was to be regarded in the light of a true exponent of the character of the invention, its claims to confidence must certainly be abandoned.

The cause of this unfavorable result was attributed by the inventor to the supposed presence of oxide or other impurities in the metal, but a much more probable cause was discovered when it was stated that these same disks had been previously employed in his experiments made while exhibiting his apparatus. As the true character of alloys, that of yielding to combined heat and pressure a portion of their more fusible contents while the remainder exhibits far less than the original fusibility of the compound, had not been recognised by the inventor, nor any adjustment of the length of screw on the top of his valve-stem, adapted to meet this variable character of fusible compounds, it was evident that, whatever might have been the degree of uniformity in the action of these disks during the early trials to which they had been subjected, they could no longer exhibit that uniformity when urged to the extent of exhaustion now attempted, much less if still farther compressed by the *followers* or hard metal disks, which had been procured by the inventor for forcing out the last portions of alloy from the cups.

On inspecting samples of the materials from which the alloys had been composed, there was found no reason to suspect any essential impurity, except a little dross in the bismuth, which could be got rid of by the simple expedient of remelting the mass and pouring it free from the oxidized portion.

SECOND SERIES.

A pair of disks was next provided, composed of equal parts of tin and bismuth about half an inch in thickness. These were put in place, and the arrangements having been completed, a brisk fire was kindled and the steam raised as rapidly as possible. When it had attained a pressure of $63\frac{1}{2}$ pounds on the safety-valve, the flue-valve was found to be giving exit to the water. The safety-valve was raised, and the pressure reduced to about 48 pounds, when the metal was found sufficiently hard in the cups to allow the flue-valve to be screwed up and held in place. The fire was again urged, and in about four minutes the water again escaped; the weight on the safety-valve lever remaining as before, at $63\frac{1}{2}$ pounds. In this way, by alternately lowering the pressure to screw up the valve, and then permitting the steam to rise and be blown off through the safety-valve under the same weight, *twelve* actions of the flue-valve were procured without setting the weight beyond the notch for $63\frac{1}{2}$ pounds. But it was evident that, toward the last of these actions, the escape of steam through the safety-valve was required to be much more rapid than at first, in order that the valve should be made to act: in other words, that the actual pressure within the boiler should be carried beyond $63\frac{1}{2}$ pounds before that action could be attained.

After the twelfth action of the valve, the steam escaped rapidly for more than ten minutes without farther influence on the fusible disks. The weight on the safety-valve was then increased to 70 pounds, but still no escape of water occurred, nor did any appear until the pressure had been augmented to 80 pounds. Here the escape of water was very limited, and could barely be distinguished by the slight hissing noise occasionally produced. Subsequently the load on the safety-valve was augmented to 136 pounds before the *fourteenth* and last action of the flue-valve could be produced. After its occurrence the disks had become so far exhausted as to allow the screw-nut to come in contact with the shoulder on the valve-stem, and, of course, no farther action could be obtained. The contents of the boiler must, in such cases, escape. The difficulty of fusion had in this case increased from $63\frac{1}{2}$ to 136, or *one hundred and fifteen per cent.*, as indicated by the pressure. The average thickness of the residuary disks was .2 of an inch. The two sets of experiments already detailed, had rendered it abundantly evident that, in the construction of his apparatus, the inventor had not taken into his account that peculiar character of fusible alloys which had been referred to in the French ordinance, which had been so well elucidated by Mr. Rudberg's researches,* and more recently with a view to another form of apparatus for preventing explosions, had been laboriously traced by a committee of the Franklin Institute at Philadelphia.† Not having contemplated the necessity of providing against the presence in the cups of alloy, of a considerable quantity of metal, which could only be fused at a temperature far higher than that at which the first portions would be forced out by pressure, but having, on the contrary, been under the impression that the expulsion of a limited quantity of alloy from the cups during a single action of the valve, was caused solely by the ready liquefaction of that part of the disk which was in contract with the iron of the flue, and the slower melting of the upper parts, he had not duly regulated the length of the screw on the stem of his flue-valve, so as to terminate its range of action before the more infusible parts of the metal should be brought into play. With this defect in the arrangement, had it been attempted to put the apparatus into practical use, it must certainly have failed to fulfil its intended purpose, and have justified the rejection of fusible alloys when acted upon by heat and pressure together, as had already been done by one of the parties who had previously examined the subject.‡ The degree of uncertainty which would soon have been found to mark its action, might then possibly have been cited as evidence that there were in "physical science" principles claiming to be "fixed, certain, and inevitable," which could not be relied upon in *practice*. It might have given color to the fallacious notion, so often promulgated by the advocates of mere routine, that science is of no avail to the practical man.

In order to illustrate the nature of the different residua obtained in the two series of trials above detailed, the temperatures of solidification of each portion were separately tried, as above described, and with the following results:

The metal of the old disks derived from an alloy composed of six parts, by weight, of tin, and four of bismuth, having been melted in oil, began to lose fluidity, and exhibit a slight granulation, at 370° Fahrenheit—was brittle and crumbling at 345°, and hard at 360°. The metal which had oozed out round the bottom of the cups, and been found adhering to them after the conclusion of the experiments on the same alloy, continued fluid down to 307°—was permanently impressed at 284°—was a soft solid at 274°—lost its power to reunite detached masses at 264°—and became hard at 260°; showing a range of temperature from fluidity to hardness of no less than 47 degrees.

A small button of alloy taken from the bottom of the boiler, showed signs of granulation at 262°—was permanently impressed at 246°—ceased to form pools in cavities at 218°—ceased to reunite detached masses at 214°—and was barely hardened at 210°.

The following table exhibits the character of the residues derived from the second series of trials:

* Annales de Chimée et de Physique, volume 48.
† See report on the explosion of steam-boilers, Franklin Institute, 1836.
‡ Committee of the Franklin Institute, pages 23-39.

TABLE I.

Temperatures observed during the solidification of different portions of a alloy composed originally of equal parts, by weight of tin and bismut after being used fourteen times in the boiler under pressures from 63 to 136 pounds on the safety-valve.

Part of the alloy under trial.	Temperature of incipient granulation.	Becomes permanently impressed.	Ceases to form pools in cavities.	Ceases to reunite detached masses.	Becomes hard.	Range from fluidity to hardness.
	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degree
1. Old disk - -	346	328	–	310	306	4
2. Original alloy - -	291	280	263	258	254	3
3. Beads adhering to the cups after the 14th trial -	296	278	–	–	266	3
4. Small plate after trial under $63\frac{1}{2}$ pounds on the safety-valve - -	272	247				
5. Large plate after 12th trial - - -	276	258	–	–	242	3

THIRD SERIES.

A modified form of cups with bottoms of hard metal (instead of bein open below to allow the fusible disk to rest directly on the iron of the flue and with a few small holes around the bases to permit the fused metal to es cape, was next used; and having been filled to the depth of seven tenths o an inch with an alloy composed, like the last, of equal parts of tin and bis muth, the inventor proposed to determine whether more uniform results coul not be obtained than when the fusible metal was allowed to escape throug notches around the bases of the cups. Greater depth was also given to th disks, in order to determine what proportion of the metal would be easil fused, and how much must be allowed for as infusible residuum when th screw-nut reached the shoulder on the valve-stem. As this was the questio on which turned the entire usefulness of the invention, a question whic had not to my knowledge been previously submitted to any decisive exami nation, it was deemed expedient to give it such an investigation as shoul furnish practical results, as well as useful knowledge in regard to the gener subject of alloys.

By measuring the thickness of the disks before and after the trial, the rela tion of the *expressed* portion of the alloy, to the whole quantity of the mix ture, was ascertained, and by observing the time elapsed between consecutiv actions of the flue-valve, and occasionally noting the reduction of pressur after each action, some conception is afforded of the rapidity with which suc actions may be made to succeed each other. The effect of a rapid and slow combustion is likewise illustrated. In a series of observations at the commencement of this set of trials a brisk combustion being maintained, it was ascertained that the pressure rose from 28 to 68 pounds, at a nearly uniform rate of five pounds per minute.

The *first* action of the flue-valve occurred at $69\frac{1}{2}$ pounds.

The *second*,	after reducing	the pressure to	$53\frac{1}{2}$,	occurred in	4 min.	at $63\frac{1}{2}$ lbs.
The *third*,	"	"	50,	"	5 "	$63\frac{1}{2}$ "
The *fourth*,	"	"	53,	"	2 "	$58\frac{1}{2}$ "
The *fifth*,	"	"	$48\frac{1}{2}$,	"	$6\frac{1}{2}$ "	$63\frac{1}{2}$ "
The *sixth*,	"	"	58,	"	$4\frac{1}{2}$ "	$69\frac{1}{2}$ "
The *seventh*,	"	"	$63\frac{1}{2}$,	"	20 "	$73\frac{1}{2}$ "
The *eighth*,	"	"	$48\frac{1}{2}$,	"	$24\frac{1}{2}$ "	$75\frac{1}{2}$ "

As the fusibility of the alloy had now evidently begun to diminish, as evinced not only by the increased weight on the safety-valve, but also by the greater length of time which was required to obtain the last two results, and the small space through which the screw-driver could be turned in raising the valve after the latter actions, it was determined to discontinue the series, and after cooling off the boiler, to take out and measure the disks. They were found reduced in the one case to .3, and in the other to .35 inch in thickness, showing a mean of $53\frac{1}{2}$ per cent. diminution by eight successive actions of the valve, under pressures varying from $58\frac{1}{2}$ to $73\frac{1}{2}$ pounds on the safety-valve. Hence, it appears, that this alloy may be safely employed by allowing about half its thickness for infusible residuum. Having collected, and preserved for trial, the drops or beads adhering to the cups, and which were, of course, supposed to represent the fusibility of the last flow or ooze of metal in the preceding trials, as well as some buttons of alloy found in the bottom of the boiler, the cups were replaced in order still further to test the character of the residua.

A weight of 75 pounds on the safety-valve allowed the steam to escape in about 45 minutes after kindling the fire. The weight was successively increased to 80, 90, and 100 pounds, the steam being allowed to escape for some time under each weight. In about one minute after the last-mentioned weight was applied the flue-valve acted. The safety-valve was raised, and the tension of steam reduced to 90 pounds.

A *second* action occurred in 8 minutes, with a pressure of 110 pounds.

A *third* action took place in eight minutes, under 120 pounds.

After again reducing the pressure to 90 pounds, it was gradually carried up in the course of 20 minutes to $141\frac{1}{4}$ pounds, when as the *increase* of pressure was $82\frac{3}{4}$ pounds, or 141 per cent. of $58\frac{1}{2}$, the lowest weight under which the valve has acted, it was not thought necessary to push farther the trials on this residuum. Again the cups were removed and measured, when they were found to contain .325 of an inch of fusible alloy. One of the residuary disks was melted out of its cup, and with the last running of *expressed* metal, together with the original alloy, and the beads previously gathered, was tried in hot oil to determine the relative temperatures of solidification. These will be seen in the annexed table, where it may be remarked that the commencement of granulation in the metal of the exhausted disk is 74 degrees higher than that of the original alloy, and that part of the metal exuded from the disks during the second series of trials has a fusing point three degrees higher than the same original mixture.

TABLE II.

Temperatures observed during the solidification of the different parts the alloy, composed of equal parts of tin and bismuth, after two series trials in the boiler, under pressures varying in the first from $58\frac{1}{2}$ *to* 7 *pounds ; and in the second from* 100 *to* 141 *pounds. Original thic ness* .7 *inch ; after trial* .325 *inch ; loss* $53\frac{1}{2}$ *per cent.*

Part of the alloy under trial.	Temperature of incipient granulation.	Metal permanently impressed.	Ceases to form pools in cavities.	Ceases to reunite detached masses.	Becomes hard.	Range from fluidity to
	Deg's.	Deg's.	Deg's.	Deg's.	Deg's.	Deg
1. The old exhausted disk after a second series, under a final pressure of $141\frac{1}{4}$ pounds - - -	365	357	–	344	326	
2. Original alloy of one part of tin and one of bismuth	291	280	263	258	254	
3. Plate taken from the boiler after the final use of the disks, under a pressure of $141\frac{1}{2}$ pounds - -	294	280	–	260	258	
4. Beads adhering to cups after the first set of trials, under $73\frac{1}{2}$ pounds -	276	268	–	$245\frac{1}{2}$	240	3
5. Beads round the cups but not adhering after first series of trials - -	274	265	–	242	238	3
6. Plate taken out from the bottom of the boiler after the first series - -	276	262	–	240	236	4

FOURTH SERIES.

The near proximity of the last three portions of exuded metal to ea other, in point of melting temperature, suggested the propriety of procuri alloys for purposes similar to that now under consideration, by using on the portions which had been forced out of mixed masses by the combin effect of heat and pressure. A considerable mass of exuded metal, deriv principally from alloys of tin and bismuth, and which had escaped noti while the inventor had been exhibiting, previous to my examination, t action of his apparatus, afforded me an opportunity of putting this mat to the test, by causing two disks to be cast from that compound. As it e hibited a fracture of crystalline structure, there seemed a probability of its being, to some extent, a chemical compound.

Each disk was made .7 inch thick, and of the same diameter ($1\frac{1}{4}$ inch) as all the preceding. The following series of actions then occurred:

Discharge				Time			Lbs. pressure.
1st	discharge of	water took	place in	50	min. after lighting the fire, at		$27\frac{1}{2}$
2d	"	"	"	3	min. after that, at	-	$27\frac{1}{2}$
3d	"	"	"	4	"	-	$27\frac{1}{2}$
4th	"	"	"	5	"	-	$27\frac{1}{2}$
5th	"	"	"	6	"	-	30.4
6th	"	"	"	4	"	-	30.4
7th	"	"	"	3	"	-	32
8th	"	"	"	$10\frac{1}{2}$	"	(fire moderate)	33.3
9th	"	"	"	$8\frac{1}{2}$	"	(fire more rapid)	33.3
10th	"	"	"	5	"	" -	33.3
11th	"	"	"	9	"	" -	34
12th	"	"	"	4	"	" -	36.5
13th	"	"	"	1	"	(pressure kept up)	37.5
14th	"	"	"	4	"	" -	38.5
15th	"	"	"	2	"	" -	39.5
16th and last		"	"	9	"	" -	40

As the pressure had now increased 12.5 pounds, or 45.4 per cent. above what was required at the beginning, the series was concluded. When subsequently taken out and examined, the residuum in the cups was found to be .18 inch thick. On the under sides of the disks were observed several cavities from which the more fusible metal had flowed, leaving the harder portions in a porous, honeycomb state. This appearance being produced in succession at the several meltings which the disks undergo, and subsequently obliterated in part, as higher pressures and temperatures are employed, may serve to explain a very constant phenomenon attending the fusion of the disks, taken out after the experiments in the boiler had been completed. This consisted of a certain sputtering sound like that of frying meat, which was sometimes so marked as to throw up bubbles of considerable magnitude in the melting mass. It did not entirely cease until some time after the whole was in fusion; which seems to imply, that the water to which it is owing, is not merely mixed mechanically, and imprisoned in the cells of porous metal, but in part also combined chemically with the ingredients of the alloy. The same effect was produced in melting the plates taken from the bottom of the boiler, and remarkably so with that from which the last pair of disks had been prepared.

The above series of results will be perceived to justify the anticipation, that the exuded portions of an alloy may be relied on to furnish a greater range of action to the flue-valve, than can generally be obtained by mixtures made in the ordinary way. The reduction in thickness from .7 to .18 of an inch, or 74.3 of the total amount, is considerably more advantageous than either of the preceding trials.

In this, as in a preceding alloy, the effect of heat and pressure on the subsequent melting temperature of different parts will, as seen in the following table, be found to give a far less fusibility to the residuum in the cups, than to the mixture from which the disks had been cast:

TABLE III.

Temperatures of solidification observed in different parts of the above alloy composed of lead, tin, and bismuth, in uncertain proportions, which had been withdrawn from the boiler, after having been forced out of disks of various composition, cast into a pair of cups, filling them .7 inch, left after trial .18 inch; tried under pressures from 27.5 to 40 pounds on the safety-valve. Sixteen trials being made within those limits of pressure.

Part of the alloy under trial.	Temperature of incipient granulation.	Metal permanently impressed.	Pools cease to be formed in cavities.	Ceases to reunite after separation of parties.	Becomes hard.	Range from fluidity to hardness.
	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
1. Old disks - - -	292	275	260	255	250	42
2. Original compound as taken from the boiler, determined by two successive trials - - - -	249	243	-	-	226	23
	251	245	-	-	224	27
3. Beads adhering to the cups	264	252	-	246	242	22
4. Large plate from the bottom of the boiler - -	243	232	-	-	216	27

FIFTH SERIES.

Having established the point that an alloy of tin and bismuth in equal parts by weight would give an action to the flue-valve until about one half exhausted, and that even a greater proportion of an alloy prepared by the process of *pressure at a high temperature* could be rendered available for the same purpose, it became an inquiry of some interest to ascertain what results would be afforded by other proportions of tin and bismuth; also whether in melting those materials together in various proportions, any essential difference in fusibility would be possessed by the compounds. For this and other purposes, two pairs of disks, each pair composed of ten parts by weight of tin and twelve of bismuth, were prepared. The first pair gave the following series, each disk being at first about .4 inch thick:

The 1st action took place when the pressure was			at 61 lbs. on the safety-valve.		
" 2d, after a lapse of	$2\frac{1}{2}$	minutes, when at	60	"	"
" 3d,	5	" "	63	"	"
" 4th, (fire brisk),	4	" "	$63\frac{1}{2}$	"	"
" 5th	$5\frac{1}{2}$	" "	63	"	"
" 6th, (fire moderate,)	$5\frac{1}{2}$	" "	$61\frac{1}{2}$	"	"
" 7th,	6	" "	$63\frac{1}{2}$	"	"
" 8th,	6	" "	65	"	"
" 9th,	4	" "	65	"	"
Mean	-	-	62.83	"	"
				"	"

When withdrawn, after cooling off the boiler, these disks were found to have been very unequally melted; that which had been nearest the fire-end of the flue being almost entirely exhausted, while the other preserved nearly its original thickness. About 50 per cent. was the mean loss. The residue furnished the following table:

TABLE IV.

Temperatures observed during the solidification of different parts of an alloy composed of ten parts, by weight, of tin and twelve of bismuth, after having been subjected to action in the boiler nine times, under pressures from 61 to 65 lbs. on the safety-valve.

Parts of the alloy under trial.	Temperature of incipient granulation.	Metal permanently impressed.	Ceases to form pools in cavities.	Ceases to reunite detached masses.	Becomes hard.	Range from fluidity to hardness.
	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.
1. Old disk, the one almost exhausted - -	313	306	286	280	278	35
2. Original alloy - -	295	285	272	265	263	32
3. Beads adhering to the cups	271	265	256	254	252	19
4. Plate from the bottom of the boiler - -	270	363	255	252	250	20

SIXTH SERIES.

The second pair of disks was formed with greater thickness than the preceding, being .65 inch and of the same proportions.

The 1st action of the flue-valve occurred when the pressure had risen, by the action of a rapid fire, to - - - - - 60 lbs.

The 2d,	after the lapse of 3 minutes, at	-	-	$58\frac{1}{2}$ lbs
" 3d,	" 5 "	-	-	$63\frac{1}{2}$ "
" 4th, (fire slow),	" 11 "	-	-	56 "
" 5th,	" 1 "	-	-	55.5 "
" 6th,	" 3 "	-	-	$57\frac{1}{2}$ "
" 7th,	" 2 "	-	-	56 "
" 8th,	" 10 "	-	-	$58\frac{1}{2}$ "
" 9th,	" 2 "	-	-	$64\frac{1}{2}$ "

Previous to this series, the legs of the brace which held up the flue-valv had been so shortened as to leave an allowance of .32 of an inch for residuu in the cups after the screw-nut reached the shoulder of the valve stem. Th series was, therefore, concluded in a manner similar to that which must oc cur in practice after the disks shall have become exhausted. The wate escaped through the flue-valve, and all attempts to screw it up were of cour unavailing. One half of the metal was left in the cups. The mean pre sure for the nine experiments in the last series is 58.88 lbs. on the safety valve, while that of the preceding series, with the same number of exper ments, is 62.83 lbs. This difference may probably be attributed to th production of a greater quantity of oxide in one case than in the other whi fusing the two metals to form the alloy. The temperatures of solidificatio will also be found considerably lower in the second than in the first trial this alloy.

TABLE V.

Temperatures observed during the solidification of different parts of an allo composed of ten parts, by weight, of tin and twelve of bismuth, after ha ing been subjected to action in the boiler nine times, under pressures vary ing from 60 to $64\frac{1}{2}$ lbs. on the safety-valve.

Parts of the alloy under trial.	Temperature of incipient granulation.	Metal permanently impressed.	Ceases to form pools in cavities.	Ceases to reunite detached masses.	Becomes hard.	Range of temperature from fluidity to hardness.
	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degre
1. Old disks - -	271	265	259	254	251	2
2. Original alloy -	269	260	–	–	252	*1
	268	258	251	–	251	
3. Beads adhering to the cups - - -	270	268	–	–	†250	2
4. Plate from the bottom of the boiler - -	263	258	252	250	249	1

* Metal crusts over and becomes hard almost immediately.
† Becomes stationary when bulb is in the melted metal.

SEVENTH SERIES.

The exuded metal taken from the boiler in the two preceding sets, melted together and cast into disks, afforded another opportunity of proving the quality of metal obtained solely by such a process; and is by so much the more worthy of attention than the example previously given, as in *this* case the nature of the constituents is more certainly known. With these disks, the following series was obtained:

The 1st action occurred when the pressure was - - $52\frac{1}{2}$ lbs.
The 2d, in 3 minutes after, when at - - $51\frac{1}{2}$ "
The 3d, 3 " " - - $51\frac{1}{2}$ "
The 4th, 3 " " - - $53\frac{1}{2}$ "
The 5th (with a brisk fire), $2\frac{1}{2}$ " " - - $54\frac{1}{2}$ "
The 6th (with a brisk fire), $2\frac{1}{2}$ " " - - $54\frac{1}{2}$ "
The 7th, 4 " " - - $54\frac{1}{2}$ "
The 8th (fire slow), 4 " " - - 55

The metal being now so far exhausted, that the valve could no longer be brought to its bearing, the series was necessarily terminated.

On comparing the mean pressure of this series with those of the two sets from which the alloy to form these disks was derived, we find that—

The first series, with 10 parts of tin and 12 bismuth, gave 62.83 pounds.

The second series, with 10 parts of tin and 12 bismuth, gave 58.88 pounds.

And the series from disks formed of *expressed* metal, of the two, 53.43 pounds.

TABLE VI.

Temperatures observed during the solidification of different parts, derived from two disks formed of an alloy composed of two plates taken out of the boiler, after using two alloys, made up of tin and bismuth, in the proportion of 10 *of the former to* 12 *of the latter—used in the boiler,* 8 *times under pressures, from* $51\frac{1}{2}$ *to* 55 *pounds. Original thickness,* .3 *inch—after trial,* .16.

Part of the alloy under trial.	Temperature of incipient granulation.	Metal permanently impressed.	Ceases to form pools in cavities.	Ceases to reunite detached masses.	Hard.	Range from fluidity to hardness.
	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.
1. Old disks - -	268	258	251	248	247	21
2. Original alloy	263	258	252	250	249	14
	270	263	255	252	250	20
3. Beads adhering to the cups	264	258	$247\frac{1}{2}$	*	246	18
4. Smaller plate from the bottom of the boiler -	264	257	246	*	244	20
5. Larger plate - -	262	258	246	*	244	18

* No granular state.

It is to be observed, that the increase of pressure in the first trial of alloy, composed of 10 tin, and 12 bismuth, extended from 60 to 65 pounds in 9 trials; in the second, from 56 to $64\frac{1}{2}$ pounds in 9 trials; and in the mixed oozes of the two, only from $51\frac{1}{2}$ to 55 pounds in 8 trials; from which it is manifest, that more uniformity of action is obtained in the last, than in either of the other two cases.

The little extent of range between fluidity and hardness observed in taking the temperatures of solidification in the three foregoing series, the near approach to uniformity in the results, when tried under the pressure of steam, and the ready formation of crystalline masses, both on the surface and in the interior, of buttons, while taking their temperatures at the moment the point of granulation had been reached, all lead to the supposition that a true chemical compound was obtained in the exuded portions of the two pairs of disks. This supposition derives strength from the fact that the proportion of 10 parts, by weight, of tin to 12 of bismuth, is almost exactly that of one atom of the former, to one atom of the latter metal.

To ascertain what effect a departure, in either direction, from these proportions would produce upon the uniformity of action, or on the first pressure which would give a flow of metal, two other mixtures of tin and bismuth were successively tried, as follows:

EIGHTH SERIES.

In this the proportion of bismuth was increased, the mixture being formed of 10 tin to 14 bismuth, each disk was .5 inch thick.

The 1st action of the flue-valve took place under	-	-	$58\frac{1}{2}$ lbs.
The 2d (after letting off steam), took place in 10 min., under			$58\frac{1}{2}$ "
The 3d,	$5\frac{1}{2}$	"	60 "
The 4th,	$6\frac{1}{2}$	"	61 "
The 5th,	4	"	62 "
The 6th (after reducing pressure to 50 lbs.),	8	"	61 "
The 7th,	9	"	63 "
The 8th (with a brisk fire),	9	"	$63\frac{1}{2}$ "
The 9th (fire more moderate),	2	"	$62\frac{1}{2}$ "
The 10th,	5	"	$63\frac{1}{2}$ "

When withdrawn, after the termination of this series, the two disks were found unequally exhausted, but by no means so unequally as the two pairs which had been composed of tin and bismuth, in the proportion of 10 to 12. In the present case, the disk nearest the fire-end of the flue, had a thickness of .14, and the other of .25 inch, the mean of which, deducted from the original thickness, shows a loss of 60 per cent. of the alloy, in the form of exudation, during 10 trials. The mean pressure is 61.35 pounds, and the *difference*, from first to last, 5 pounds. The residue of the disks was exceedingly brittle.

TABLE VII.

Temperatures observed during the solidification of the different parts of the above alloy, composed originally of 10 *parts, by weight, of tin and* 14 *of bismuth, after having been subjected to action* 10 *times, under pressures from* $58\frac{1}{2}$ *to* $63\frac{1}{2}$ *pounds, on the safety-valve.*

Part of the alloy under trial.	Temperature of incipient granulation.	Metal permanently impressed.	Ceases to form pools in cavities.	Ceases to reunite detached masses.	Becomes hard.	Range from fluidity to hardness.
	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
1. Old disk remelted, and freed from dross -	309	294	263	259	257	52
2. Original alloy - -	292	269	255	254	253	39
3. Beads adhering to the cups - - -	262	257	248	*	248	16
4. Plate from the bottom of the boiler - -	261	242	237	228	226	35

* No "sandy" appearance.

Hence it appears that neither in the action of the disks, nor in the fusing temperature of the several products taken from the boiler, is a very material alteration produced by increasing the bismuth from 12 to 14. We have already seen that a compound of equal parts of tin and bismuth (10 to 10) gave at eight experiments, in the *third series*, a mean result of 66.81 lbs. pressure; that in the second series, a similar mixture had given a number of actions very nearly identical, under a pressure of $63\frac{1}{2}$ lbs.—the former being produced in cups with bottoms, and the latter without them.

NINTH SERIES.

This was performed on a pair of disks, composed of 21 parts of tin to 10 of bismuth, .3 inch in thickness.

The *first* action of the flue valve occurred under $53\frac{1}{2}$ lbs. pressure.

The *second* (with a brisk fire), in	2	minutes after,	$57\frac{1}{2}$	“
The *third* “	3	“	$58\frac{1}{2}$	“
The *fourth*	4	“	60	“
The *fifth* (fire moderate),	4	“	61	“
The *sixth* “	4	“	$61\frac{1}{2}$	“
The *seventh*	8	“	70	“
The *eighth*	3	“	73	“
The *ninth* (after letting off steam to $58\frac{1}{3}$, and with brisk fire), in	$4\frac{1}{2}$	minutes after,	74	“
The *tenth*	7	“	80	“
The *eleventh*	$7\frac{1}{2}$	“	79	“

The *twelfth* (fire rapid,	in $10\frac{1}{2}$	minutes after, under	88	lbs. pressure.
The *thirteenth* (fire slackened),	$5\frac{1}{2}$	"	94	"
The *fourteenth*	13	"	94	"
The *fifteenth* (fire moderate),	9	"	112	"
The *sixteenth* "	12	"	130	"

The last action of the valve was so sluggish as to give exit to but little water, and scarcely to produce any effective alarm. When taken out, the disks were .15 inch thick, and the loss 50 per cent.

TABLE VIII.

Temperatures observed during the solidification of different parts of an alloy, composed of 12 *parts, by weight, of tin and* 10 *of bismuth, after being used in the boiler* 16 *times, under pressures from* $53\frac{1}{2}$ *to* 130 *pounds on the safety-valve.*

Part of the alloy under trial.	Temperature of incipient granulation.	Metal permanently impressed.	Ceases to form pools in cavities.	Ceases to reunite detached masses.	Becomes hard.	Range from fluidity to hardness.
	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.
1. Old disk - -	372	362	349	340	338	34*
2. Original metal - -	312	302	284	274	266	46
3. Beads adhering to cups -	288	272	268	262	260	28
4. Small plate - -	295	279	269	260	256	39
5. Large plate - -	288	228	218	208	206	52

* Blackened very much in the oil.

From an examination of the first nine experiments in the ninth series, it will be seen that the mean pressure under which the valve acted was 63.2 lbs., being comparable in this part with the same number of trials on several other proportions of the same metals. This series goes still further to strengthen the probability that the portion first exuded is a definite chemical compound, which, as long as it flows without much obstruction from the rest of the disk, gives nearly uniform results. At higher temperatures, its solvent power on the remaining mixture may cause it to take along, in its efflux, a portion of the less fusible parts, causing the residues to become more and more infusible at every operation.

TENTH SERIES.

The next trial was made with a view of ascertaining the character of a compound of lead and bismuth as affected by the method of pressure at incipient fusion.

The two metals were employed in equal weights, and the disks of this mixture were three tenths of an inch in thickness. By putting copper disks above those of alloy, the latter could be carried to a greater degree of exhaustion than would otherwise have been practicable, owing to the shoulder on the valve stem.

The *first* action occurred under a weight of $48\frac{1}{2}$ pounds.

The *second*	" (after reducing pressure 10 pounds)	in 9 minutes,	$48\frac{1}{2}$ lbs.
The *third*	" (after reducing pressure 10 pounds)	in 5 "	$48\frac{1}{2}$ lbs.
The *fourth*	" (after reducing pressure 10 pounds)	in 12 "	$53\frac{1}{2}$ lbs.
The *fifth*	" (pressure rising gradually)	in $12\frac{1}{2}$ "	$63\frac{1}{2}$ lbs.

After the conclusion of this series the disks were found *one tenth of an inch* thick, and had consequently lost 66 per cent. The mean pressure is $52\frac{1}{2}$ pounds, and lower, therefore, by about 10 pounds, than the mean of series 2, 3, 5, 6, 8, and 9, which is 62.6 pounds.

The disks when removed from the boiler were found, on being remelted, to granulate at 304 degrees, to be permanently impressed at 300 degrees, to cease reuniting detached masses at 283 degrees, and to become hard at 274 degrees, showing a range of 30 degrees from fluidity to hardness.

The beads adhering to the cups granulated slightly at 272 degrees, were permanently impressed at 252 degrees, and became hard at 242 degrees, showing in this part also a range of 30 degrees.

ELEVENTH SERIES.

Having made trial of both lead and bismuth, and tin bismuth by equal weights, a like proportion of lead and tin was next tried by casting a pair of disks about .47 inch in thickness, formed of equal parts by weight of those materials. At two successive trials of these disks, the pressure under which the valve acted was 252 pounds *on the safety-valve.* Only the disk nearest to the fire end of the flue appeared, even under this high pressure, to have yielded any flow of metal, the other being barely softened, and thus made to apply its lower surface more closely to the iron of the flue. Only some beads adhering to the cups could be certainly identified as having been derived from the alloy under trial. The disk which had been melted when afterward tried in oil, began to granulate at 393 degrees, was permanently impressed at 366 degrees, ceased to form pools of fluid in cavities at 348 degrees, and then almost immediately became hard at 346 degrees.

The beads which had exuded began to granulate at 348 degrees, ceased to form pools at 342 degrees, and were hard at 338 degrees, showing a range of only 10 degrees between the fluidity and the hardness of this *expressed* metal.

TWELFTH SERIES.

Another proportion of lead and tin was now employed consisting of 8 of the former to 9 of the latter metal. This was cast into disks of .77 inch in thickness.

The *first* action of the valve took place when the pressure was 242 pounds.

The *second*	action after	5	minutes	"	"	242	"
The *third*	"	$1\frac{1}{2}$	"	"	"	242	"
The *fourth*	"	2	"	"	"	240	"
The *fifth*	"	3	"	"	"	240	"
The *sixth*	"	4	"	"	"	240	"

The *seventh* action	after	2	minutes when	the	pressure was	240 pounds.
The *eighth*	"	$1\frac{1}{2}$	"	"	"	241 "
The *ninth*	"	$2\frac{1}{2}$	"	"	"	241 "
The *tenth*	"	3	"	"	"	241 "
The *eleventh*	"	4	"	"	"	241 "
The *twelfth*	"	2	"	"	"	241 "
The *thirteenth*	"	5	"	"	"	240 "
The *fourteenth*	"	3	"	"	"	240 "
The *fifteenth*	"	9	"	"	"	239 "

The composition of the above alloy was very nearly in the proportion of one atom of lead to two of tin; for 8 : 9 :: 103.6 : 116.55, whereas 2 atoms of tin = 117.8. The almost entire uniformity of action throughout the series indicates the homogeneousness of the compound. The series was discontinued from the water getting low at the time, not on account of the exhaustion of the disks, one of which was found .43 and the other .55 inch thick, the thinner one being nearest the fire-end of the flue. The proportion of metal lost is consequently 36.3 per cent. The exuded metal appeared to have undergone just enough of fusion to flow from the mass *under pressure*, but not sufficient to give it perfect fluidity, hence the greater part was found adhering to the cups.

TABLE IX.

Temperatures observed during the solidification of different parts of an alloy composed of 24 *parts of lead and* 27 *of tin, after being used fifteen times in the boiler under pressures from* 239 *to* 242 *pounds on the safety-valve.*

Part of the alloy under trial.	Temperature of incipient granulation.	Metal permanently impressed.	Ceases to form pools in cavities.	Ceases to reunite detached masses.	Becomes hard.	Range from fluidity to hardness.
	Deg's.	Deg's.	Deg's.	Deg's.	Deg's.	Deg's.
1. Old disk - - -	386	360	331	326	324	62
2. Original alloy - -	371	360	351	350	*350	21
3. Metal adhering to the cups	356	353	346	342	340	16
4. Small button, the only part found in the bottom of the boiler - - -	336	332	301	290	285	51

* Crystallizes in large masses.

It was remarked that, while in fusion under oil, none of these parts exhibited any tendency to enter into combination with the oil. This, and the short range of only sixteen degrees between hardness and fluidity in the portions adhering to the cups, indicate the existence of a true chemical compound. As it is known that the various alloys of tin and lead have, in the progress of cooling, stationary temperatures, sensibly the same for many different mixtures, it is evident that a wide range of differences can not be expected in the action of such combinations, when subjected to the joint influence of heat and pressure; and, as it has been shown that the alloys of tin and bismuth, through a considerable range of differences of composition, were capable of producing useful effects only within very narrow limits, it became necessary to try a series of compounds formed of three elements.

For this purpose, lead, tin, and bismuth, were employed, first in equal parts, and afterward diminishing the amount of bismuth by one sixteenth part, at each successive trial. In trying one of these proportions, cups of different sizes were employed as already mentioned, with a view to ascertain what advantage might result from an increase of pressure on a given area of the alloy. It will be seen that, increasing the area of the disks 2.81 times, caused an augmentation of pressure to be required, in order to force out the fluid parts from 52 to 64 pounds, or 12 pounds on the safety-valve, corresponding, as afterward shown, to about nine degrees of temperature.

TABLE X.

Tabular view of the results of 21 series of trials of alloys of lead, tin, alloy, as originally compounded, began to exhibit traces of granular tex

Number of the series.	Composition of the alloy.			Date of the trial.	Number of actions of the flue-valve.	Weights on the safety-valve at the several actions of the times as great as the contempo							
	Parts of lead.	Parts of tin.	Parts of bismuth.			Expt. 1st.	Expt. 2d.	Expt. 3d.	Expt. 4th.	Expt. 5th.	Expt. 6th.	Expt. 7th.	Expt. 8th.
				1842.									
13	16	16	16	Ap'l 30	5	27	22	23¼	24⅜	25⅝	-	-	-
14	16	16	15	May 12	5	36	33½	37½	35	41	-	-	-
15	16	16	14	Ap'l 30	7	36	34	33½	35½	36½	37½	a39½	-
16	16	16	13	May 11	12	48½	50½	52½	53½	52	52½	52	53½
17	16	16	12	11	5	49½	51	51	52½	c53½	-	-	-
d18	16	16	12	16	12	-	-	-	-	-	51	51	52¼
19	16	16	11	10	10	46	46	46	46	47	48½	48½	53½
e20	16	16	11	16	11	-	-	-	-	-	-	-	-
21	16	16	10	10	11	51	54½	54½	58½	70	72½	72½	80
22	16	16	9	9	11	51	55	56	58	58½	63½	61	63½
23	16	16	8	23	9	64	64½	64½	64½	66	69	75	87½
g24	16	16	8	9	18	53½	56	61	63½	69	70	71	75
h25	16	16	8	18	16	52½	53½	52½	53½	56	58½	62½	63½
26	16	16	7	6	14	75	75	82	85	85	85	87½	90
27	16	16	6	6	16	100	100	100	101	102½	102½	105	105
28	16	16	5	5	16	110	110	110	115	117½	120	122	122
29	16	16	4	5	20	130	130	138½	138½	143½	141	142	146
30	16	16	3	4	12	150¼	154¼	154½	168	164	164	164	162½
31	16	16	2	4	18	186	190	191	191	191	186	186	194
32	16	16	1	2	10	209	215	216½	216½	216½	217	223	223
33	8	16	8	25	7	100	102	106	110	130	146	148½	-

a After the 7th action of the flue-valve, the metal was too far exhausted to permit the valve to be made tight.

b The nut came to the shoulder of the screw, after the 12th trial, and water escaped.

c Water escaped after 5th action of the flue-valve—screw stopped.

d This series is intended to show to what extent the preceding one has exhausted the disks—by 5 trials.

TABLE X.

and bismuth, in different proportions, with the temperature at which each ture in the commencement of solidification after being fused.

flue-valve in each series, in pounds avoirdupois, being 1.648 raneous pressures per square inch.													Fusing point of the alloy at beginning of the series.	Expenditure of alloy during the series.		
Expt. 9th.	Expt. 10th.	Expt. 11th.	Expt. 12th.	Expt. 13th.	Expt. 14th.	Expt. 15th.	Expt. 16th.	Expt. 17th.	Expt. 18th.	Expt. 19th.	Expt. 20th.	Expt. 21st.		Thickness of disks at the beginning of the series.	Thickness at the end of the series.	Per centage of loss in thickness.
													Deg's.	Inch.	Inch.	
–	–	–	–	–	–	–	–	–	–	–	–	–	270	.365	.190	47.9
–	–	–	–	–	–	–	–	–	–	–	–	–	283	.640	.260	59.3
–	–	–	–	–	–	–	–	–	–	–	–	–	287	.370	.200	46.0
63½	63½	64	*b*68	–	–	–	–	–	–	–	–	–	295	.650	.290	55.3
–	–	–	–	–	–	–	–	–	–	–	–	–	297	.700	.450	55.7
56	58½	60	63½	80	95	96	103	107	–	–	–	–	302	.450	.160	41.4
57	57½	–	–	–	–	–	–	–	–	–	–	–	289	.550	.330	40.0
–	–	58	58½	58½	61	75	83	92½	95	108	112	120	316	.330	.160	30.9
90	90	94	–	–	–	–	–	–	–	–	–	–	293	.560	.300	46.4
75	77½	80	–	–	–	–	–	–	–	–	–	–	302	.525	.365	30.5
*f*100	–	–	–	–	–	–	–	–	–	–	–	–	300	.295	.130	55.9
77	80	82	85	90	91	100	101	101	105	–	–	–	301	1.050	.675	35.7
63½	69	75	80	75	76	80	80	–	–	–	–	–	301	.750	.540	29.5
90	92	95	100	108	120	–	–	–	–	–	–	–	303	.650	.285	56.1
106	107½	108	110	120	120	122	125	–	–	–	–	–	316	.650	.350	46.1
122	122½	125	127	132⅛	137¼	152	–	–	–	–	–	–	316	.600	.300	50.0
146	146	150	152	153½	154½	154½	156	156	157	158½	160	–	327	.600	.290	51.6
163	167½	162½	167½	–	–	–	–	–	–	–	–	–	343	.550	.400	27.2
194	196	198	198	200	200	200	200½	200½	202*i*	–	–	–	350	.500	.320	36.0
224	225	–	–	–	–	–	–	–	–	–	–	–	360	.450	.200	55.5
–	–	–	–	–	–	–	–	–	–	–	–	–	334	.325	.160	56.7

e Series to show the exhausion by 10 trials in the preceding set.
f After the 9th action steam escaped instead of water.
g This series was made in cups three quarters of an inch in diameter.
h The metal of the preceding series, viz., plate beads and disks melted, and recast into the same cups (three quarters of an inch).
i Water below the top of the flue after the 18th action.

The 17th series of the table shows, that an alloy composed of 4 lead, 4 tin, and 3 bismuth, may in the course of five successive actions of the flue-valve, lose 33.7 per cent. of its substance; and the 18th series, which is a continuation of the preceding, after taking out and measuring the disks, shows that eleven subsequent trials expended 41.4 per cent. of the alloy; making in all, 77.1 per cent. under pressures increasing from 49½ to 107 pounds on the safety-valve.

Series 19th and 20th give analogous information in regard to an alloy of 16 lead, 16 tin, and 11 bismuth, the former showing that 10 trials at pressures between 46 and 57½ pounds on the safety-valve, caused an exudation of metal equal to forty per cent., and that 11 subsequent trials on the same disks, produced a further exhaustion of 30.9 per cent., or 70.9 per cent. by both sets of trials, the pressure having in the meantime increased from 58 to 120 pounds.

The least exhaustion of metals appears to have occurred in the 30th series, in which it amounted to but 27.2 per cent. The average loss of metal including the two cases in which double sets were made on the same disks, is 48.8 per cent. Excluding, however, series 24 and 25, which were made in cups only ¾ of an inch in diameter, the remaining 17 sets give an average of 50.6 per cent. of exhaustion. It will be observed, however, that this would not be a safe ground of calculation for the practical operation of disks manufactured as these were, by simply mixing the metals in certain proportions and melting them together.

The mean useful effect of the alloys appears to have been limited to about 35 or 40 per cent. of the entire thickness of the disks, being in one or two instances as low as 30 per cent. By employing disks formed of exuded metal, it has been shown above, that a much larger proportion than this was pressed out before the disks could be considered exhausted.

In order to exhibit the true relation between the pressures under which the disks severally acted, and the fusing point of the alloys, both before and after they had been subjected to trial, a table is added in which the observed temperature of the steam under the first and last pressure applied to each alloy is given, as well as the temperatures of each stage in the solidification of the several parts into which the alloy was separated by heat and pressure.

TABLE XI.,

Containing a synoptical view of the temperatures observed during the solidification of the several parts of twenty-one different alloys of lead, tin, and bismuth, employed in the corresponding series of trials contained in table X., together with the weight on the safety-valve at the first and last experiment of each series, and the observed temperatures of the steam under each of those weights.

Number of the series in which the alloy was used.	Composition of the alloy in parts, by weight.			Weight on the safety-valve.		Observed temperature of steam.		Original alloy as cast into the cups.						Residue of disks after trial.					
	Of lead.	Of tin.	Of bismuth.	At the first experiment of the series.	At the last experiment of the series.	Under first observed weight.	Under last weight of the series.	Incipient granulation.	Permanently impressed.	Pools cease to be formed.	Ceases to re-unite.	Becomes hard.	Range.	Incipient granulation.	Permanently impressed.	Pools cease to be formed.	Ceases to re-unite.	Becomes hard.	Range.
				Lbs.	Lbs.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg
13	16	16	16	27	25.625	254	252	270	240	–	238	225	45	287	263	245	–	236	59
14	16	16	15	36	41	261.5	266	284	275	256	251	248	36	300	292	265	256	254	41
15	16	16	14	36	39.5	261.5	265	287	266	256	251	239	48	303	293	260	254	252	51
16	16	16	13	48.5	68	272.5	286.6	295	286	278	264	261	34	312	305	291	285	279	33
17	16	16	12	49.5	53½	273	276	297	284	267	262	260	37	302	290	282	272	270	32
18	16	16	12	51	107	274	308.5	302	290	289	272	270	32	334	328	308	296	293	41
19	16	16	11	46	57.5	269.75	279.5	289	281	269	261	258	31	316	309	290	279	276	40
20	16	16	11	58	120	279.75	314.5	316	309	290	279	276	40	343	340	310	302	288	45
21	16	16	10	51	94	273.5	301	293	285	267	263	260	33	319	311	302	–	293	26
22	16	16	9	51	80	274	294.5	302	291	276	–	261	41	311	302	–	–	285	26
23	16	16	8	64	100	284.5	302.5	300	297	285	275	270	30	315	311	301	296	292	23
24	16	16	8	53.5	105	275.75	307.75	301	292	283	274	271	30	316	310	306	299	290	26
25	16	16	8	52.5	80	275	294.5	301	292	283	274	271	30	313	309	302	290	288	25
26	16	16	7	75	120	291.3	314.5	303	297	–	278	275	28	319	312	–	–	296	23
27	16	16	6	100	125	302.5	316.25	311	304	–	288	286	25	321	312	–	306	302	19
28	16	16	5	110	152	314	328.5	316	311	–	–	293	23	331	321	–	–	308	23
29	16	16	4	130	160	324	332.25	327	320	–	–	298	29	342	330	–	–	320	22
30	16	16	3	150.25	167.5	330	335.75	343	320	–	–	310	33	347	328	314	–	300	47
31	16	16	2	186	202	345.5	346.25	350	335	320	–	318	32	376	360	–	–	326	50
32	16	16	1	209	225	352.75	360.5	360	336	–	–	322	38	372	364	346	–	330	42
33	8	16	8	100	148.5	302.5	330.5	334	318	305	292	286	48	373	369	361	354	345	28

TABLE XI.—Continued.

No. of the series in which the alloy was used.	Beads adhering to cups.						Small plate from the bottom of the boiler.						Larger plate from boiler.					
	Incipient granulation.	Permanently impressed.	Pools cease to be formed.	Cease to re-unite.	Becomes hard.	Range.	Incipient granulation.	Permanently impressed.	Pools cease to be formed.	Cease to re-unite.	Becomes hard.	Range.	Incipient granulation.	Permanently impressed.	Pools cease to be formed.	Ceases to re-unite.	Becomes hard.	Range.
	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.
13	265	249	–	230	228	37	–	–	–	–	–	–	238	232	216	212	210	28
14	279	267	258	253	244	35	–	–	–	–	–	–	250	244	237	228	224	26
15	264	260	252	247	239	25	–	–	–	–	–	–	248	238	220	214	212	36
16	295	288	276	270	268	27	264	258	249	242	238	26	261	253	245	238	234	27
17	266	262	255	247	243	23	270	263	254	246	244	26	265	257	248	240	237	28
18	297	287	272	260	256	41	280	270	262	254	248	32	270	263	252	241	237	33
19	271	266	260	245	243	28	26	254	246	239	236	27	264	256.5	245.5	239	236	29
20	306	292	274	264	262	44	293	266	237	228	223	67	283	255	240	232	230	25
21	293	282	272	265	263	30	280	276	265	263	262	25	270	264	252	250	248	22
22	289	284	–	270	257	32	277	271	–	–	256	19	274	266	258	–	252	22
23	287	280	266	258	255	32	265	263	254	248	240	28	269	264	250	245	242	27
24	287	284	268	262	258	29	–8	–	–	–	–	–	282	273	260	256	251	31
25	277	273	264	253	251	26	26	229	222	212	208	58	266	206	200	188	186	80
26	298	293	284	–	270	28	296	278	–	264	260	32	289	276	265	257	254	35
27	292	238	–	–	274	18	292	288	281	–	270	24	292	282	–	264	266	32
28	306	300	–	282	280	26	304	296	288	–	278	23	303	298	–	–	280	23
29	316	310	300	–	292	24	–5	–	–	–	–	–	312	299	–	292	282	30
30	322	317	308	–	299	23	32	316	–	302	298	24	317	309	–	–	299	18
31	335	328	–	315	310	25	332	327	–	–	315	15	320	315	–	–	304	16
32	330	322	–	–	316	14	330	324	–	–	314	18	324	316	–	–	308	16
33	299	292	285	2	271	28	22	288	270	266	262	32	288	281	268	265	263	25

From the above table several useful hints may be derived, in regard to the character and mode of action of alloys, when employed in the manner proposed by Mr. Easton.

Comparing the fusing temperatures of the *original alloys*, with the observed pressures on the safety-valve, and with the pressures per square inch on the interior of a boiler, it is found, that the temperatures known to be due to the weights on the safety-valve, at the first action of the flue-valve, could have brought the whole alloy into a state of complete fusion. From this it is obvious that the effective area of the safety-valve is greater than one square inch. On taking a careful measurement of this valve, its lower base was found to contain one square inch, and the upper base 1.98 square inch. Between these two limits its *effective* area must obviously be comprehended. It was determined in a manner which will be described below to be almost exactly 1.65 square inch; showing that the lower portion of the valve did not accurately fit the seat.

2. When we compare the observed temperatures of the steam, at the first experiment in *each* series (given by a thermometer, the bulb of which descended about two and a half inches into a tube closed at bottom and opening at the top of the boiler, filled with oil or mercury), with the temperatures of solidification of the corresponding original alloys, it is found that the temperature of steam is *always* below that of *incipient granulation*, and generally by about *nine degrees;* usually below that at which the congealing metal became permanently impressed; not unfrequently about the same as that at which pools cease to be formed in cavities of the melted button, and some times nearly as low as that at which the detached masses cease to cohere firmly after separation.

3. The temperature corresponding to the pressure, at the last experiment, on each alloy contained in column 8th, has the same relation to the solidification of the residue of the disks as that of the first experiment has to the solidification of the original alloy.

4. The mean of the 21 numbers, in the 7th column of the table, is 289.7 degs.; that of the 9th, 308.6 degs.; showing that each alloy yielded its first ooze of metal at 18.9 degrees below its point of perfect fluidity.

5. The mean of the numbers in the 8th column is 305.4 degs.; that of those in the 15th, is 324.4 deg.; showing that, at the *last* oozing of each alloy, the disks were exactly nineteen degrees, on an average below their point of perfect fluidity.

6. In all the series, except five (Nos. 13, 14, 15, 24, 29), complete sets of *granulating temperatures* are found; of which the mean—

For the residuary disks is - - - -	331.5 degs.
For original alloys - - - - -	313.2 "
For beads adhering to cups - - - -	297.7 "
For smaller plates from boiler - - - -	289.5 "
For larger plates from boiler - - - -	278.4 "

7. The mean range of temperature between fluidity and hardness—

In 21 residuary disks, is - - - -	34.2 degs.
In 21 original alloys - - - - -	34.2 "
In 21 sets of adhering beads - - - -	28.3 "
In 16 small plates - - - - -	29.7 "
In 21 large plates - - - - -	29.0 "

To be able to estimate truly the effective area of the safety-valve attached to Mr. Easton's boiler during the experiments on fusible alloys it was necessary to determine the pressure per square inch, corresponding to each *pressure on the safety-valve*, during those experiments. This verification was effected by taking both the temperature and pressure of the steam. The former was ascertained by a thermometer, of which the freezing and the boiling points were carefully verified, and the inequalities of calibre determined by a detached portion of the mercurial column carried successively along to every part of the tube. The *pressure* was found by means of a manometer or air gauge about 35 inches high, graduated into 11.269 equal volumes by filling it with successive portions of mercury, and marking the same on the glass. This tube was, of course, hermetically sealed at top, cemented into an iron cup, and opening beneath the surface of mercury at bottom.

The air was dried by exposure for 15 or 20 hours over dry chloride of calcium, and when enclosed in the tube and confined over the mercury, was at a temperature of 68° and under a pressure of 30 inches. The fall of mercury in the cylindrical cast-iron cup was calculated in advance, and the diameter of the cup adjusted so as to produce a fall in the reservoir of exactly one hundredth part of the rise in the tube. The level of water in the boiler was very nearly the same as that of mercury in the reservoir. The gauge was placed more than 10 feet from the boiler, and behind a projecting part of the wall, so that no direct radiation could have come to it from the furnace, even had not a thin partition of boards still further screened it from the influence of that source of error.

In the rear of the glass tube was placed a box-wood scale divided into inches and tenths. A brass sliding band encompassed this scale and carried on its front a ring which embraced the glass tube, and by its lower edge guided the eye in determining the level of mercury in the tube. In using this apparatus, the steam was allowed to flow steadily under a given weight on the safety-valve, maintaining the combustion as uniform as practicable, and when a stationary condition of both the thermometer and gauge had been attained they were several times noted, observing also the period elapsed between consecutive observations. It was found practicable to maintain this uniform condition of things by careful management of the safety-valve, by cautiously pressing it down or tapping the lever to allow the steam to overcome the friction on the pivot about which the lever turns.

To prevent the thermometer, destined to measure the temperature, from being influenced by the conducting power of the metal of the boiler, the upper part of the latter was covered with several folds of canvass.

A thermometer suspended near the gauge-tube, gave the temperature of the air, which never varied more than two degrees during the experiments, and the deliberation with which the successive pressures were taken, gave full time for the included air to become even in temperature with that without.

The mode of calculating the pressure of steam is sufficiently simple. As it is an exact counterpoise to the column of mercury in the tube together with the elasticity of the confined air, and as the height of the former is given by observation, while the latter is inversely as the bulk of air at different states of pressure, the comparison of the observed number of volumes with that originally enclosed in the tube, gives the ratio of the pressures at the two periods, and this multiplied by thirty gives the number of inches of mercury which is equivalent to the elasticity of the enclosed air at the time of observation.

A single example will illustrate what has just been stated. Thus, when the weight on the safety-valve was 85 pounds, the temperature of the steam was 300 degrees; and the height of mercury, in the gauge, was 24.12 inches above that in the reservoir. By this rise of mercury the 11.269 volumes or measures of air had been condensed so as to occupy exactly three measures. Its elasticity was consequently 11.269-3.000, or 3.756 times as great as before. This number, multiplied by 30 inches, gives 112.69—the number of inches in the height of a column of mercury, which would *balance the elasticity of the air.* To this adding the observed height of the column of mercury in the tube, we obtain 136.81 as the total height of a column of mercury, which would make *an equilibrium with the elasticity of the steam.* To determine the pressure in pounds avoirdupois on the square inch, the weight of a column of mercury of this height must be known.

The specific gravity of mercury, at 47 degs. Fahr., is 13.568, and its expansion by 180 degrees of heat, being 1-55.5 part of its bulk, its specific gravity at 67 degrees (the temperature during my experiments), was 13.541, and 30 cubic inches of it consequently weighed 102,552.76 grains, or 14.65 pounds avoirdupois. This number is, therefore, taken to represent *one atmosphere of pressure.* As 30 inches is contained 4.56 times in 136.81 inches, 4.56 times 14.65 pounds, or 66.80 pounds is the total pressure on one square inch of the interior of the boiler. But, as there is *one atmosphere of pressure* always acting on the outside of the boiler, the amount of *bursting pressure*, or that which tends to raise the safety-valve, is known by taking 14.65 pounds from 66.8 pounds, leaving 52.15, the number contained in the 9th column of the table. Hence it appears that the ratio between the weight on the safety-valve and the bursting pressure is 85-52.15, or 1.629—which is the *effective area* of that valve.

In the accompanying table (XII.), column 11th gives these areas as determined under the respective weights to which the valve was subjected. The mean of 44 trials is 1.648. It will be remarked that in some instances the same weight was employed through a considerable range of pressures. This is readily accounted for by considering that, at one time, the valve may be partly in contact with and resting on its seat, while at another it may be wholly sustained by the stronger current of effluent steam; and that in both cases it may give exit to all the steam produced at the time by the existing combustion. This difference of pressures under the same weight on the valve, was particularly noticed at the higher temperatures, when the leaks of the boiler served to give vent to no inconsiderable part of the steam which escaped.

TABLE XII,

Exhibiting the true temperature and elasticity of steam at pressures extending both above and below the points at which all the preceding experiments on fusible alloys were made, intended to verify the value of the conical safety-valve employed in those experiments, and to determine the actual pressures to which the alloys were subjected.

No. of experiment.	Weight on safety-valve.	Temperature by thermometer in steam.	Volumes of air in gauge.	Height of mercury above level of fountain in inches.	Elasticity of air in inches of mercury.	Total elasticity of steam in inches of mercury.	Elasticity of steam in atmospheres of 30 inches of mercury.	Pressure on a square inch in lbs. above a vacuum.	Pressure per square inch above one atmosphere.	Effective area of safety-valve in square inches.	State of temperature and pressure.
		Degrees.									
1	14.5	237.75	8.437	7.77	40.07	47.84	1.595	23.36	8.71	1.636	Steady for 4 minutes.
2	16.375	240.25	8.050	8.72	42.00	50.72	1.690	24.75	10.10	1.621	Steady 1 minute.
3	18.69	243	7.689	9.80	43.96	53.76	1.792	26.25	11.60	1.610	
4	21	246	7.392	10.79	45.734	56.524	1.884	27.60	12.95	1.621	Steady 5 minutes.
5	24	250	6.920	12.11	48.780	60.89	2.029	29.72	15.07	1.592	Steady 3 minutes.
6	32.5	258.5	6.000	14.93	56.340	71.275	2.375	34.79	20.14	1.613	Steady 5 minutes.
7	33.5	258.75	5.950	14.98	56.858	71.838	2.394	35.07	20.42	1.640	
8	43.5	269.5	5.000	17.99	67.61	85.60	2.853	41.79	27.14	1.603	Steady 4½ minutes.
9	59.5	282	4.000	21.09	84.51	105.60	3.520	51.57	36.92	1.611	Steady 3 minutes.
10	80	296.5	3.177	23.58	106.41	129.99	4.333	63.48	48.83	1.638	
11	85	300	3.000	24.12	112.69	136.81	4.560	66.80	52.15	1.629	
12	90	301.75	2.955	24.27	114.40	138.67	4.622	68.71	54.06	1.664	
13	95	304	2.789	24.85	121.21	146.06	4.868	71.31	56.66	1.676	
14	110	314	2.409	26.00	140.75	166.75	5.558	81.42	66.77	1.647	
15	110	314.25	2.393	26.05	141.27	167.32	5.577	81.71	67.06	1.640	
16	115	315	2.367	26.13	142.91	169.04	5.634	82.54	67.89	1.694	
17	115	315.25	2.308	26.31	146.47	172.78	5.759	84.37	69.72	1.649	
18	117.5	315.5	2.306	26.315	146.604	172.919	5.764	84.44	69.79	1.733	
19	120	316.3	2.296	26.35	147.243	173.593	5.786	84.76	70.11	1.711	
20	120	316.5	2.290	26.37	147.63	174.00	5.800	84.97	70.32	1.706	
21	120	319	2.185	26.69	154.72	181.41	6.047	88.59	73.94	1.623	
22	120	322	2.096	26.98	161.29	188.27	6.275	91.93	77.28	1.546	

TABLE XII—Continued.

No. of experiment.	Weight on safety-valve.	Temperature by thermometer in steam.	Volumes of air in gauge.	Height of mercury above level of fountain in inches.	Elasticity of air in inches of mercury.	Total elasticity of steam in inches of mercury.	Elasticity of steam in atmospheres of 30 inches of mercury.	Pressure on a square inch in lbs. above a vacuum.	Pressure per square inch above one atmosphere.	Effective area of safety-valve in square inches.	State of temperature and pressure.
		Degrees.									
23	130	324	2.020	27.21	167.36	194.57	6.486	95.02	80.37	1.617	Steady 2 minutes.
24	134	330	1.864	27.68	181.37	209.05	6.968	102.08	87.43	1.531	
25	154	333.25	1.735	28.09	194.85	222.94	7.431	108.86	94.21	1.634	
26	174	340	1.558	28.64	216.92	245.56	8.185	119.91	105.26	1.653	
27	193	351	1.322	29.38	248.16	277.54	9.251	135.53	120.88	1.596	
28	193	352	1.318	29.40	256.50	285.90	9.530	139.61	124.96	1.544	
29	193	352.5	1.306	29.43	258.86	288.29	9.609	140.77	126.12	1.530	
30	213	355	1.251	29.60	270.24	299.84	9.995	146.42	131.77	1.601	
31	233	362	1.129	29.98	299.44	329.42	10.981	160.87	145.22	1.604	
32	233	363	1.116	30.02	302.84	332.86	11.095	162.54	147.89	1.575	
33	233	363.75	1.080	30.14	313.61	343.75	11.458	167.86	153.21	1.520	
34	254	366.75	1.061	30.23	321.66	351.89	11.729	171.83	157.18	1.609	
35	287.75	371.5	1.000	30.39	338.07	368.46	12.282	179.93	165.28	1.740	Steady 5 minutes.
36	314.75	378	0.903	30.69	374.38	405.07	13.502	197.80	183.15	1.719	
37	314.75	378.75	0.900	30.70	375.63	406.33	13.544	198.42	183.77	1.712	
38	314.75	380	0.894	30.72	378.16	408.88	13.629	199.66	185.01	1.701	Steady 1 minute.
39	350.75	382	0.865	30.81	390.83	421.64	14.055	205.90	191.25	1.834	
40	350.75	382.5	0.862	30.82	392.19	423.01	14.100	206.56	191.91	1.827	
41	350.75	385.5	0.820	30.95	412.28	443.23	13.774	216.44	201.79	1.738	
42	350.75	385	0.813	30.97	415.83	446.80	14.893	218.18	203.53	1.723	
43	350.75	386.5	0.803	31.00	421.00	452.00	15.066	220.71	206.16	1.701	
44	350.75	388	0.800	31.01	422.58	453.59	15.119	221.49	206.80	1.695	
								Mean	. .	1.648	

Accompanying the table is a scale of the elasticity and temperature of steam at the time the several alloys were tested. It extends, however, both above and below the actual range of trials on fusible metals. On the same scale are placed that of Dr. Ure, that of the French academicians, and that of the committee of the Franklin Institute. The points observed during my experiments will be seen to conform very nearly with those obtained by Dr. Ure, so far as the latter extend, which is, however, only to five and a half atmospheres. Throughout the range of my experiments the pressures are higher, for the same temperatures, than those obtained by MM. Arago and Dulong. Between five and a half and ten atmospheres, the line of my observations lies between those of the French Academy and those of the Franklin Institute. At a temperature of three hundred and eighty-eight degrees, the highest point reached by my observations, the difference from the French savans is .9 of an atmosphere. By the formula of Tredgold, as adopted by the Franklin Institute, the difference at the same temperatures would be about one and a half atmospheres. On the left of the scale will be found the composition of the alloys which yielded for the first time at the temperatures opposite to which they severally stand.

Having now exhibited the character of this invention, so far as the same depends on the nature of fusible alloys, and verified, by two methods, the degrees of heat and pressure to which each sample of those materials was subjected during trial—having shown the limits within which a good degree of certainty may exist in regard to the action of alloys, and described the experiments which illustrate the utility of the proposed method of preparing fusible compounds—it remains to mention some of the objections which have been suggested either against the principle or the application of this invention.

1. *Fusible alloys have, it is alleged, a degree of uncertainty in their action, which ought to preclude them from use in so important an apparatus as one for preventing explosions.*

To this a reply is furnished by the experiments, which show that within proper limits the uncertainty of action is not such as to interfere with a useful application of those materials. All the compounds tried yielded portions more fusible than the rest, whenever the temperature and pressure, required in each case, had been attained. Neither in re-casting the disks, nor in repeated melting of the alloys in oil, did it appear that any essential alteration took place. The presence of a portion of oxide with an alloy, appeared to lower rather than raise the point of fusion.

2. *The opening of a valve in the top of a flue must, in general, discharge water and not steam, and thereby tend, in addition to retaining the great reservoir of latent heat, to produce an evil more dangerous than even a high pressure of steam, as it would allow the naked iron to become overheated before the boiler could be replenished.*

This objection can be obviated by placing the disks, as at present, on the surface of the flue, and putting between the legs of the brace, which sustains the valve, a steam-box, into which the valve should open *above the water level.* Such box might extend nearly to the top of the boiler, and open either into the flue, or by a pipe through any convenient part of the outer shell.

3. *Being wholly within the boiler, the apparatus can not be reached without extinguishing the fires, emptying the boiler, and opening the man-hole.*

To this the reply is, that the melting point of the disks ought never to be reached in ordinary practice; and never ought they to act except when wilful mismanagement has endangered the safety of the boiler. Hence they furnish precisely that species of check upon unprincipled misconduct which consists in repaying with inconvenience and discomfiture the recklessness which would sport with the comfort, property, and lives of others. If never mismanaged, the alloy would last during the whole existence of the boiler, especially if forfeiture of his situation by the engineer were made the consequence of allowing the disks to act even for a single time during his engagement.

4th. *If an engineer, disposed to risk the safety of his boiler, should prepare beforehand for such a course, by putting a solid support beneath the brace which sustains the flue-valve, the latter would not act, however much of the alloy might be melted out of the cups.*

This species of tampering in advance might be prevented by the manufacturer of the boiler, were he to enclose the whole apparatus in a sheet iron cage riveted to the flue, and only allowing a passage through the top for the driving rod, with a few small apertures for the circulation of water and steam.

5th. *The apparatus if applied to boilers without flues must have the disks and valve on the bottom, where sediment would accumulate over, and impede the action of the valve, or prevent its being screwed up after having once acted.*

Whatever force may be in this objection, would be obviated by the means already suggested to prevent the escape of water. The feet of the brace would rest on disks at the bottom of the boiler, while the steam-box to receive the valve would open near its top.

6th. *It can not be known from inspection how often the disks may have been allowed to act, and whether they have become so far exhausted as to be on the point of giving out, either through want of metal or want of fusibility in that which remains.*

This defect might easily be remedied by cutting, on the upper part of the driving rod, just below the winch, a few threads of screw of the same length as those on the valve stem, and causing it to pass through a fixed nut outside of the boiler. By marking the height of this rod above the top of the boiler when the apparatus is first put in place, the distance it may have subsequently been driven down will be apparent.

7th. *Being wholly within the boiler, and, in the case of steamboats, out of the view of passengers, it could not inspire so much confidence as those forms of apparatus which lie within the reach of observation.*

This objection goes only to the reputation, not to the real character of the invention. It is to be offset by the advantage of also lying out of the reach of wilful interference.

In conclusion, I may remark, that Mr. Easton's apparatus if modified and applied in the modes above suggested, appears much better calculated to fulfil its purpose, than the disks or plugs of fusible alloy employed in France. With those precautions, including an accurate adjustment of the shoulder on the valve stem, and a due preparation of the alloys themselves, it would, I conceive, be adequate to prevent the explosion of any steam boiler. Since the above investigation has been in progress, the inventor has amended in several respects his specification, including therein other forms of apparatus for accomplishing his object. As these are not understood to be included in the resolution of the Senate, I hasten to lay before you the results of my labors, that you may be able to obey the injunction of that body to report the same with the least practicable delay.

All which is respectfully submitted.

WALTER R. JOHNSON.

ELASTIC FORCE OF STEAM

PRESSURE IN ATMOSPHERES